DecaWave:
Exploring State of the Art Commercial Localization

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ABSTRACT

In developing technology for indoor localization, we have recently begun exploring commercially available state of the art localization technologies. The DecaWave DW1000 is a new ultra-wideband transceiver that advertises high-precision indoor pairwise ranging between modules with errors as low as 10 cm. We are currently exploring this technology to automate obtaining anchor ground-truth locations for other indoor localization systems. Anchor positioning is a constrained version of indoor localization, with minimal time constraints and static devices. However, as we intend to include the DW1000 hardware on our own localization system, this provides an opportunity for gathering performance data for a commercially-enabled localization system deployed by a third-party for comparison purposes. We do not claim the ranging hardware as our original work, but we do provide a hardware implementation, an infrastructure for converting pairwise measurements to locations, and the front-end for viewing the results.

1. INTRODUCTION

Ultra-wideband (UWB) RF location systems have historically shown position accuracy superior to that of all narrowband techniques, yet have not seen widespread interest. In contrast to narrowband techniques, positioning systems built on UWB are inherently difficult to design, as the timing circuitry requires custom IC design or expensive off-the-shelf devices. Stovepiped UWB location systems such as Ubisense [3] and Time Domain [2] have been around since 2009, but are poorly suited for RF localization research. The DecaWave ScenSor DW1000 [1], however, provides a commercially available UWB transceiver IC with all required location primitives built-in as shown in Figure 1. The transceiver is able to provide timestamps for incoming packets and time-of-flight measurements—the two primitives necessary for time-based location systems—thus enabling future research in next-generation UWB location systems.

2. SYSTEM OVERVIEW

Ranging (measuring the distance between two nodes) is provided as one of the core functionalities of the DecaWave transceiver. Due to the inherent difficulty in keeping accurate long-term time synchronization between nodes, DecaWave uses a time-of-flight (ToF) approach to cancel out any offsets in absolute time that may be present between the nodes performing ranging. Figure 2 illustrates the ToF ranging concept to determine the range between two nodes, A and B. Instead of determining distance based on the immeasurable RF propagation time from A to B $((T_{ii} - T_i) * c)$, the ToF approach used by the DW1000 calculates range based on both the two-way propagation time and a known turnaround time at node B $(((T_{iv} - T_i) - (T_{iii} - T_{ii})) * c/2)$.

Microsoft Indoor Localization Competition. Apr 13–17, 2015, Seattle, WA.

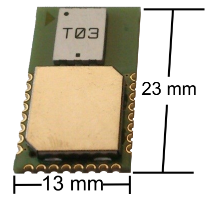


Figure 1: Integrated DecaWave DW1000 hardware module.

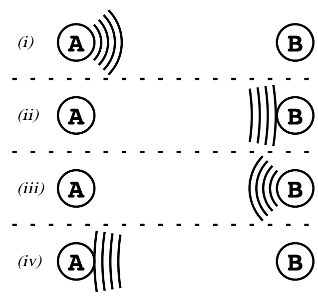


Figure 2: Visualization of time-of-flight (ToF) ranging. When nodes A and B are synchronized, only one ToF estimate is needed in order to form a range estimate $((T_{ii} - T_i) * c)$. In the case of no synchronization, node A can use the round-trip time-of-flight to calculate the range to B $(((T_{iv} - T_i) - (T_{iii} - T_{ii})) * c/2)$.

Range-based measurements between the device to be localized (tag) and multiple fixed-location devices (anchors) can be used to determine the tag's location via trilateration if the position of the anchors is known. As demonstrated in Figure 3, given the position of three anchors and the range between each anchor and the tag, the single point where the three circles of equidistance meet give the tag's estimated position. The location system as presented will extend the same approach to three dimensions when performing location operations.

3. DECAWAVE'S TECHNOLOGY

The key to acquiring accurate packet timestamp information in indoor environments lies in the ability of the receiver to distinguish the first line-of-sight packet reception from any following echoes due to multipath. Figure 4 illustrates the complexity of the indoor propagation channel and the importance of determining the arrival time of the direct line-of-sight path instead of the arrival time of the (potentially) much longer multipath propagation paths.

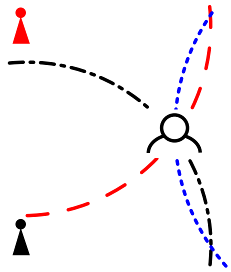
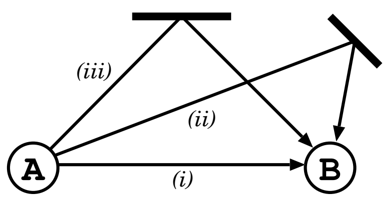
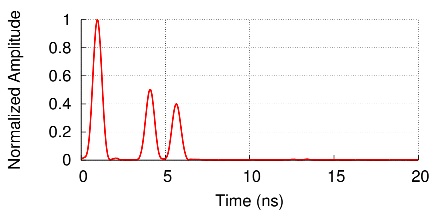


Figure 3: Trilateration principles. Range-based measurements between the tag and anchor create a sphere that defines a surface of possible tag locations. Here we show 2D trilateration for simplicity, where range measurements are sufficient to constrain tag location to intersecting circles.



(a) Multipath Diagram



(b) Multipath Impulse Response

Figure 4: Example of a multipath environment. *(i)* is the direct line-of-sight (LoS) path, where *(ii)* and *(iii)* are secondary interfering signal paths. Figure 4b shows a possible impulse response plot of three interfering paths. Ranging techniques rely on determination of the time of arrival of the LoS path, necessitating the need to distinguish it from other secondary interfering paths.

The DecaWave transceiver starts by encoding packet bits as short (ns-level) RF pulses. The short pulse duration aids in distinguishing the line-of-sight path from those following. Ideally, the pulse duration should be short enough to accurately distinguish the closest difference in distance between LoS and non-LoS propagation paths in order to avoid aliasing effects.

The timing of the pulse's reception is performed with an internal high-speed ADC and signal processing circuitry internal to the DW1000 chip. This is used to produce a high-resolution model of the RF channel's channel impulse response which is then analyzed to determine the most likely time-of-arrival of the first (line-of-sight) path. The time resolution for the time-of-arrival estimate is 15 ps, corresponding to a distance resolution of $15 \times 10^{-12} * c = 0.45$ cm.

As explained previously, just measuring the time-of-arrival of the tag's transmission at the anchor is insufficient in determining the distance between tag and anchor since the tag and anchor are not synchronized. Therefore, after a known turnaround time at the anchor, a subsequent message is sent from anchor to tag and its arrival time at the tag is calculated. After accounting for the turnaround time at the anchor, the range is determined based on the remaining in-air time-of-flight. This range product is used as the only location primitive necessary to produce location estimates in this demonstration.

4. ENTRY DETAILS

The infrastructure for this localization demo will be used in conjunction with the Luxapose [4] visual light localization system. This infrastructure consists of ceiling-mounted LED beacons embedded with a modular microcontroller-based control system. The control system for the visible light localization system will be augmented with a new layer that includes a DecaWave transceiver and associated control circuitry for supporting UWB-based localization. These UWB range-based transceivers will not only serve to self-localize the lights after installation, but will also provide a separate localization system for the embedded device class that is not well suited to use visual light based localization.

The UWB transceiver layer at each light will fill the role of a single anchor in this localization demonstration. Along with the associated power and control circuitry, the UWB transceiver will be switched between three different UWB antennas in order to avoid polarization-induced attenuation of the line-of-sight path. Range estimates between the tag and each of the anchor's three antennas will be measured. Since attenuation of the line-of-sight path primarily results in a positive error in range estimate, the shortest range estimate of the three will be kept and stored as the true line-of-sight distance between tag and anchor.

The tag will be a handheld device which will obtain ranging measurements to all anchors within communication range. These ranging measurements will then be processed on a central server to calculate the position of the tag. Given the known position of each light, and therefore each DecaWave on the light's control board, the central server will then perform localization using trilateration and store the estimates in a database for later query.

Lastly, a web-based visualization will be set up to show historic position estimates for the localization system. Exact coordinates of the last known location estimate along with a 3D visualization with an overlaid room model will be used to visualize the position estimate relative to the room's configuration.

5. MATERIALS AND SETUP

Since this localization demo shares the same infrastructure with the Luxapose demo, it will have the same setup requirements. Specifically, the localization system requires the ability to install lighting infrastructure in the demonstration area. Advanced knowledge of the facility will help to aid in properly preparing the necessary mounting hardware or a free-standing mounting structure will need to be devised.

The handheld tag will be self-contained, portable, and able to continuously perform localization operations. The tag will need a Wi-Fi connection to upload range estimates to the processing server.

6. REFERENCES

[1] ScenSor DW1000, DecaWave. http://www.decawave.com/products/dw1000.

[2] Time Domain PulsON 400 RCM. http://www.timedomain.com/p400.php.

[3] Ubisense Location Platform. http://ubisense.net/en/.

[4] Y.-S. Kuo, P. Pannuto, K.-J. Hsiao, and P. Dutta. Luxapose: Indoor positioning with mobile phones and visible light. In *The 20th Annual International Conference on Mobile Computing and Networking*, MobiCom '14, September 2014.